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TIES431 Tietokoneverkkojen jatkokurssi (3 op, 2 ov)

http://www.cc.jyu.fi/~timoh/kurssit/verkot/verkot.html

Content

- Functional aspect to the QoS in networks; components, protocols and management. The main focus will be Quality of Service in Internet.
- Requirements:
  - Complete n home exercises
  - Pass the laboratory exercise

Content

- **Course book :**

  - J. Joutsensalo, T. Hämäläinen, and A. Sayenko: "QoS Supported Networks, Scheduling, and Pricing; Theory and Applications"

- **Other useful books:**

  - Zheng Wang: "Internet Quality of Service: Architectures and Mechanisms ", ISBN: 1-55860-608-4

  – Routing in the Internet (2nd Edition) by Christian Huitema

  – W. Stallings: Data and Computer Communications, sixth edition, Prentice Hall. Chapters 12, 15, 16, 17.

  – W. Stallings: High-speed networks, TCP/IP and design principles, Prentice Hall, 1998. Chapters 11-15.

Detailed Content

1. Introduction, What and why QoS ?
2. Content :
   - QoS mechanisms: Packet classification and marking (TOS, DSCP) RFC2859, Classification overview
   - QoS mechanisms: Traffic regulation Policing and Shaping
   - QoS mechanisms: Resource sharing, scheduling (WRR, WFQ, DRR) Schedulers
   - QoS mechanisms: Congestion management (RED, WRED) RED
   - QoS mechanisms: Signalling NSIS
   - QoS architectures - Integrated Services Integrated Services in the Internet Architecture: an Overview RFC1633, RFC2990 - Next Steps for the IP QoS Architecture
   - QoS architectures - Differentiated Services: An Architecture for Differentiated Services, RFC 2475, RFC 3260 - New Terminology and Clarifications for Diffserv
   - QoS provisioning Providing QoS, Inter-Domain QoS Provisioning and Accounting
   - QoS management and monitoring (token bucket, EWMA, TSW) Monitoring, Integrated QoS monit.
   - Different applications (multicast, RT vs- NRT) MCAST CAC, Mcast
   - Adaptive scheduling models
   - QoS Frameworks
   - Open IMS

Laboratory exercise

- ” WiMAX QoS”
  - Home work, WiMAX basics
  - NS2 simulator model
  - Test simulations
  - Questions and analysis

Esimerkkejä viikkoharjoituksista/tenttikysymyksistä

- Mitä tarkoitetaan palvelun laadulla IP-verkoissa? Mitä erilaisia mekanismeja sen toteuttamiseen on?
- Montako palvelunlaatuluokkaa on mahdollista toteuttaa DiffServ-arkkitehtuurilla? Montako näistä todennäköisesti toteutetaan tavallisessa operaattori/yritysverkossa?
- Avaa ja selitä seuraavat termit. Kerro myös, mihin tarkoitukseen kutakin käytetään.
  - End-to-End delay
  - Jitter
  - Loss
  - Bandwidth
  - WFQ:
  - RED:
  - CBWFQ:
  - LLQ/PQ:
  - MQC:
  - shaping:
  - policing:

Esimerkkejä viikkoharjoituksista/tenttikysymyksistä

- Oletetaan, että yritys A haluaa omassa verkossaa käyttää palvelunlaatuominaisuuksia. He ovat pohtineet liikenteensä jakamista kolmeen eri kokonaisuuteen; VoIP, liiketoimintakriittiset sovellukset ja muu. Kuvaa lyhyesti, miten toteuttaisit QoS-ominaisuudet heidän verkossaan, kun yrityksellä on kuusi toimipistettä, jotka on yhdistetty operaattorin MPLS VPN –palvelun kautta.
- Mitä on multicast? Miten se eroaa unicastistä ja broadcastistä?
- Mistä löydät listan käytössä olevista multicast-osoitteista?
- Mikä on IGMP? Mikä versio siitä on tällä hetkellä käytössä. Kuinka se toimii?
- Kerro mitkä ovat PIM-SM ja MSDP jotka tällä hetkellä muodostavat internetin laajuisen multicast-verkon pohjan.

Introduction, Motivation, What and Why ??

- What is the BIG picture in IP QoS
- What are the small pieces that for the big picture
- Traffic differentiation and Quality of Service
- What is the difference between these two
- What have been standardized on these areas
- Why to choose this or that method/architecture for particular application
- Are there any sense to make these things

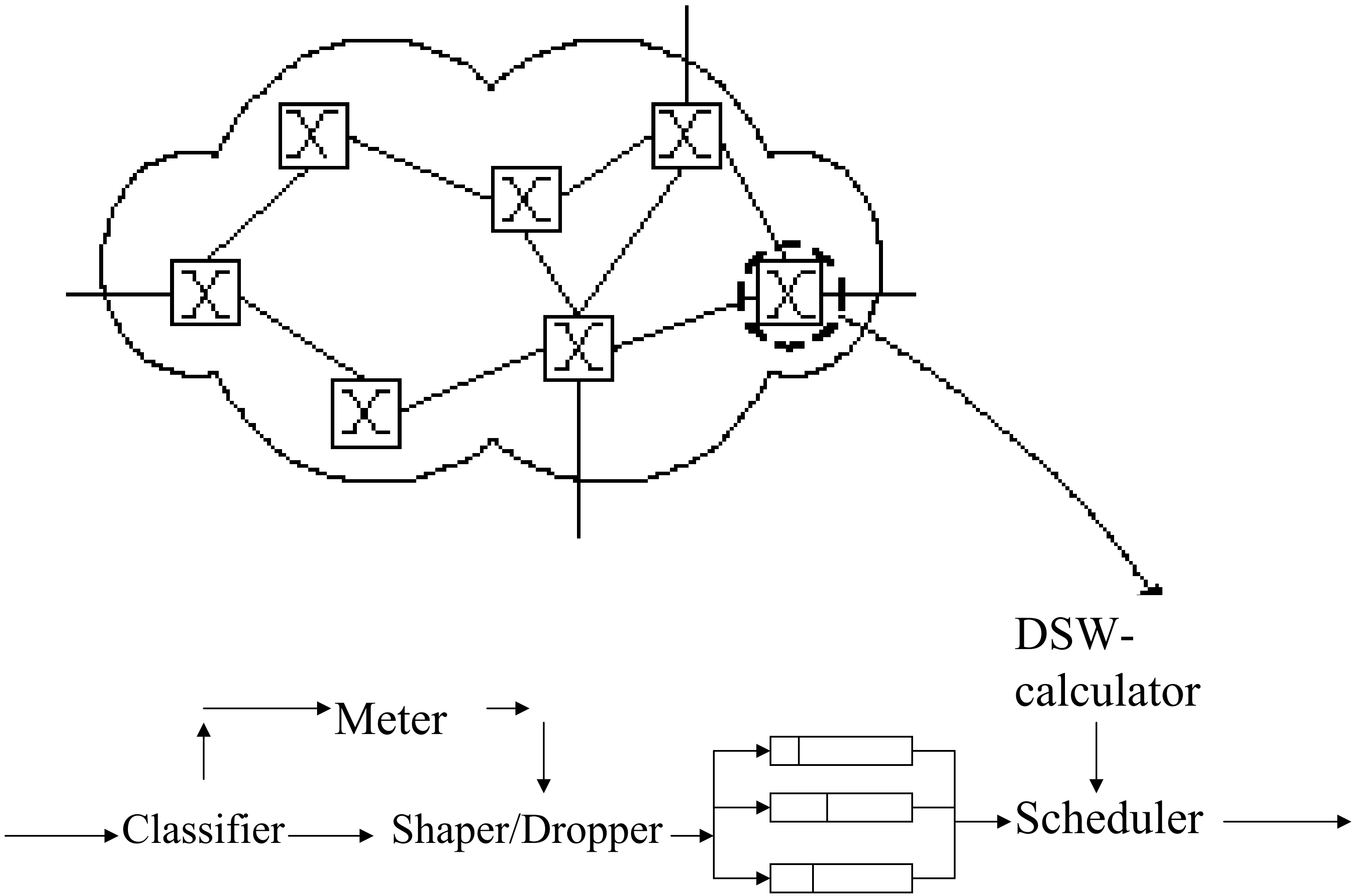
Introduction, Motivation, What and Why ??

- **Keep in mind:**
  - ISPs are there for the money
  - They don’t care about you
  - They don’t care about your applications
  - They don’t care what you are doing
  - They care about your money
- Therefore,
  - They care your opinions
  - They care that you are satisfied

Internet QoS

- Common nominator
- Separate control path
- Router is divided into layers
  - Data path (Forwarding)
  - Control path (Path & connection control)
  - Management path (Device management)
- More/less processing
- More than BE
- Less than per packet per device processing

Adaptive router



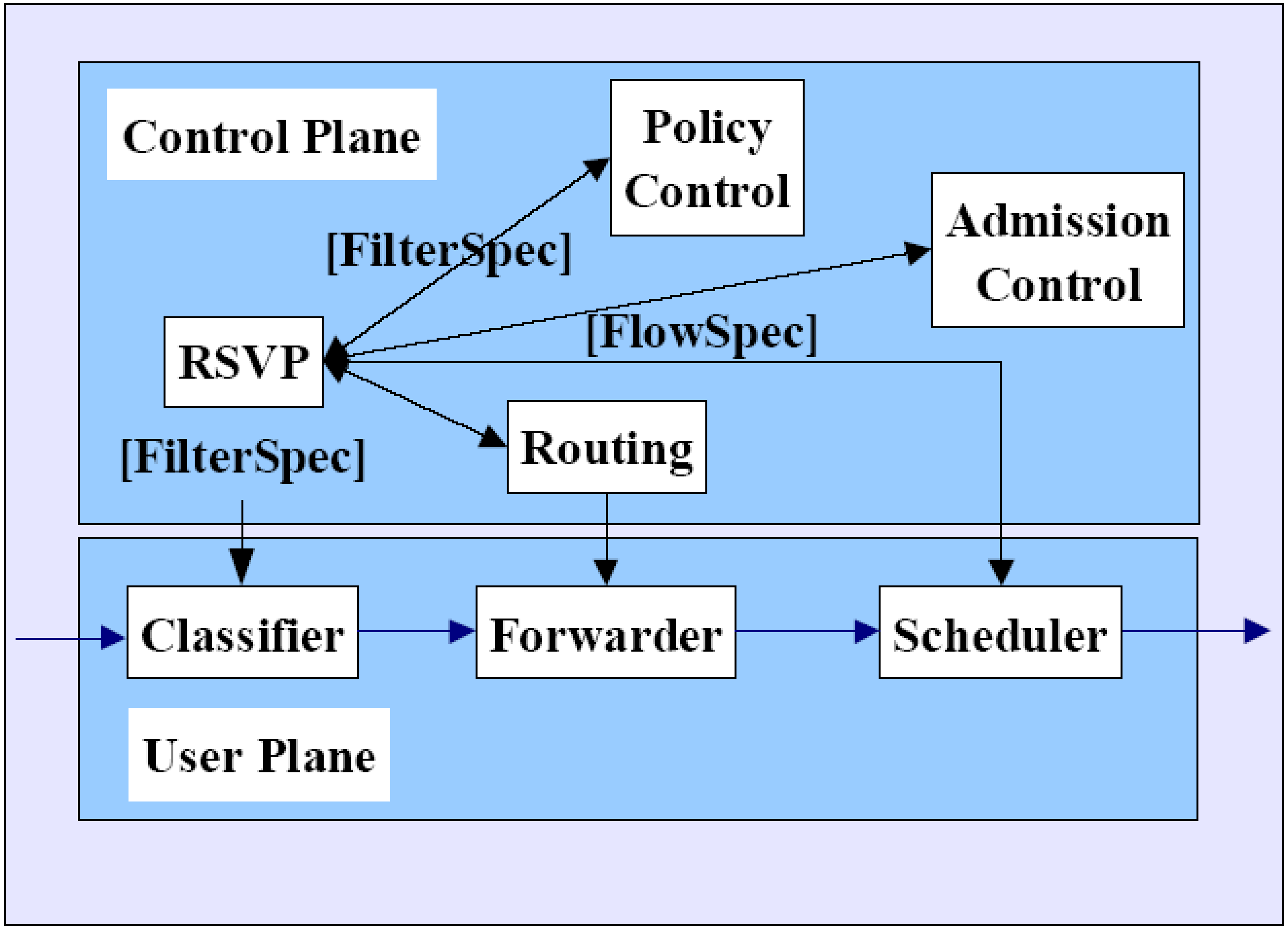
IIS – IntServ

- Connection oriented nature on top of connectionless IP
- Control path build as separate messaging sequence with the help of reservation protocol and agents
  - RSVP protocol is responsible to do actual messaging and book keeping
  - CAC agent checks to see if there is free capacity to accommodate new real–time connections

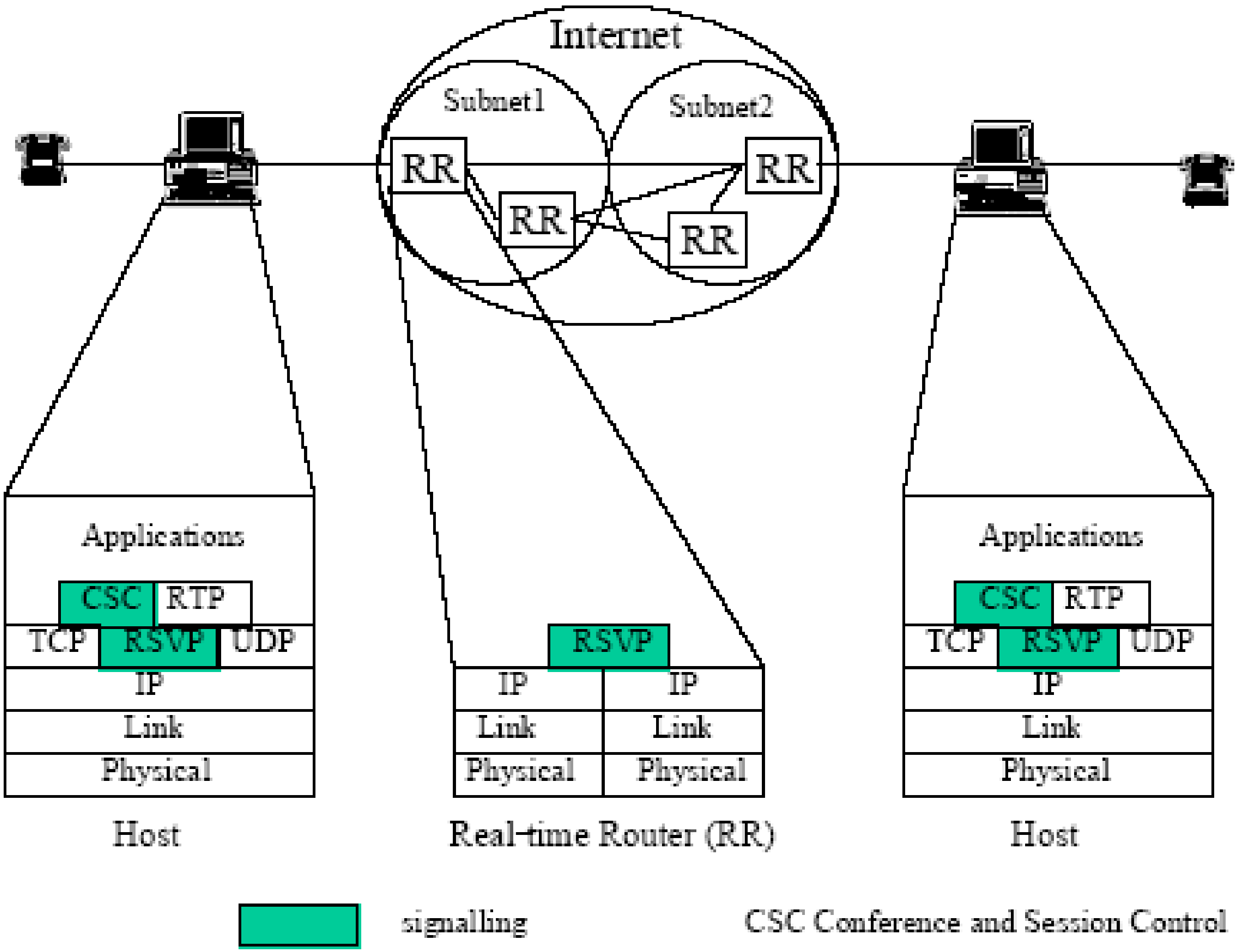
IIS – IntServ

- Connection oriented nature of IntServ requires that there is book keeping between
  - Connection identifier (FilterSpec)
  - Resources (FlowSpec)
  - Path (Route)

IIS - IntServ


Control Plane
Policy Control
Admission Control
[FilterSpec]
[FlowSpec]
RSVP
Routing
[FilterSpec]
Classifier
Forwarder
Scheduler
User Plane

IIS - IntServ


Internet
Subnet1
Subnet2
RR
RR
RR
RR
Applications
CSC
RTP
TCP
RSVP
UDP
IP
Link
Physical
Host
RSVP
IP
IP
Link
Link
Physical
Physical
Real-time Router (RR)
Applications
CSC
RTP
TCP
RSVP
UDP
IP
Link
Physical
Host
signalling
CSC Conference and Session Control

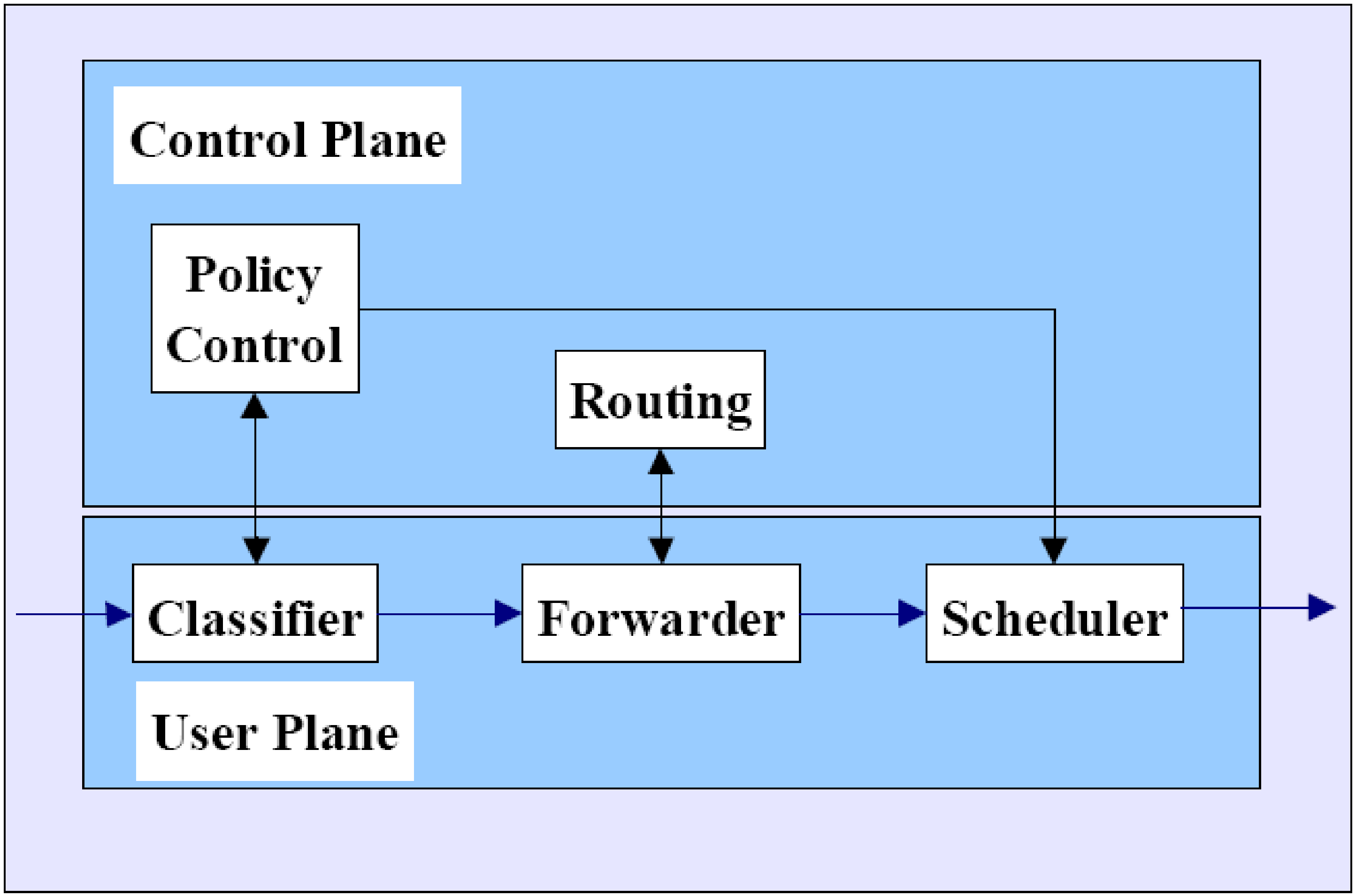
DS - DiffServ

- Connectionless class based differentiation policy build on top of IPv4
  - There is no connection control as the operation is based on the aggregates
  - Control can be build as a outside functionality with brokering functionality
  - RSVP signaling between end user and network broker to produce provisioning that resembles IntServ

DS - DiffServ

- Connectionless nature does not require per flow book keeping
  – Aggregates must be kept but they are rather static
  – Per user information is stored on the edge of the network

DS - DiffServ



Control Plane
Policy Control
Routing
Classifier
Forwarder
Scheduler
User Plane

WFQ scheduler: virtual finish time

- The finishing time of packet $k+1$ of flow i is finishing time of the previous packet plus the time to transmit the current packet

$$F_i^{k+1} = F_i^k + \frac{L_i^{k+1}}{w_i}$$

- F_i^k finishing time of packet k of flow i
- a_i^k arrival time of packet k of flow i *(WF2Q)*
- L_i^k length of packet k of flow i

WFQ virtual finish time

$$F_i^{k+1} = \max(V(a_i^{k+1}), F_i^k) + \frac{L_i^{k+1}}{w_i}$$

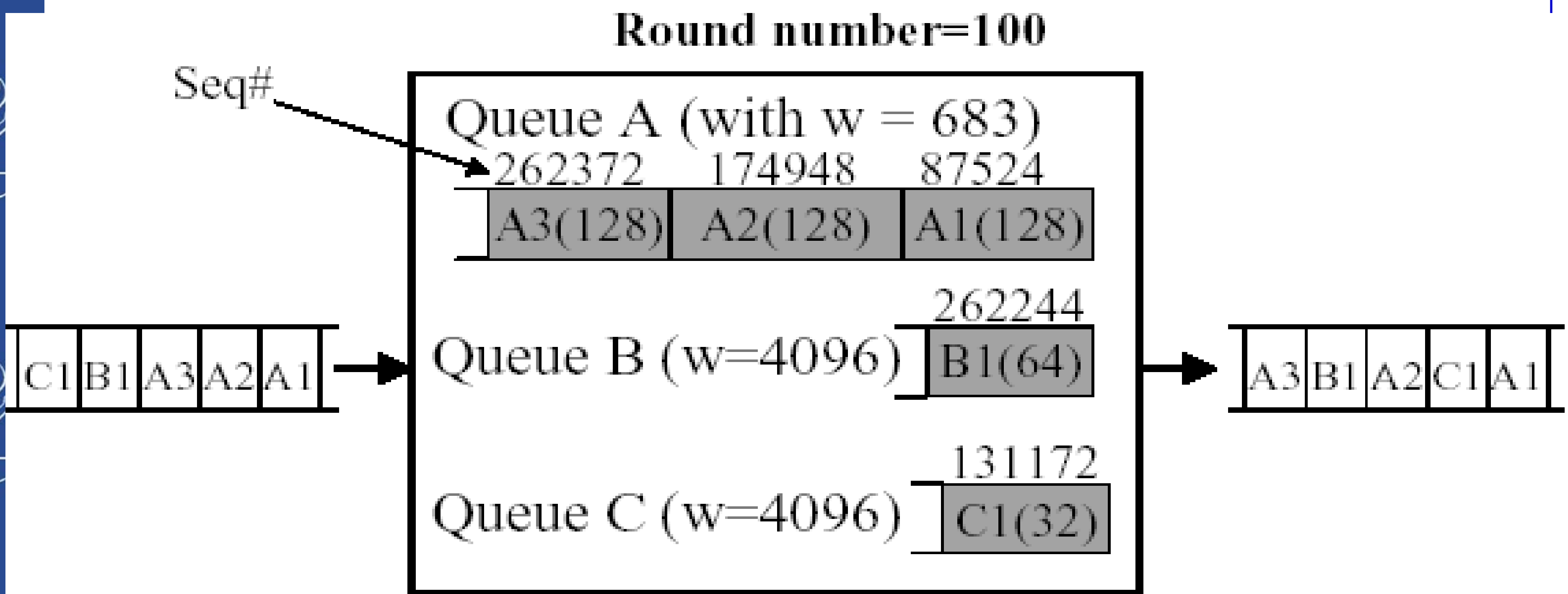
- if *exact* fairness is required, then set w_i to 1 for all flows:

$$F_i^{k+1} = \max\left(V(a_i^k), F_i^k\right) + L_i^{k+1}$$

WFQ ex.

- *Weight=4096/(IP precedence + 1)*
- the higher *w* the smaller the bandwidth
- if the packet (*k*) arrived while the flow is inactive(nonbackloogged), then the *virtual finish time* (vft):
  - Seq_k = round number + $(w_i * Size_k)$
- if the packet (*k*) arrived while the flow is active(backloogged), then the *virtual finish time* (vft)
  - $Seq_k = Seq_{K-1} + (wi * Size_k)$
  - round number is the number of bytes forwarded so far

WFQ ex.



Round number=100
Seq#
Queue A (with w = 683)
262372
174948
87524
A3(128)
A2(128)
A1(128)
262244
Queue B (w=4096)
B1(64)
131172
Queue C (w=4096)
C1(32)
C1
B1
A3
A2
A1
A3
B1
A2
C1
A1

Scheduler example: WFQ- based Load Balancing Algorithm

- WFQ scheduling policy is used (end-to-end delay bounds as well as guaranteed output rates for different traffic classes).
- Guaranteed rate for each flow in class *i* can be denoted as follows:

$$R_{i,l} = \frac{w_i B_l}{N_i} \qquad (1)$$

where $w_i B_l$ is the portion of the total bandwidth which service class *i* receives in path *l*. N_i denotes the number of *i*th class packets.

- The worst-case delay bound experienced by a packet belonging to a flow

$$D_{i,l} \le \frac{\sigma_i + 2(K-1)L_i}{\rho_i} + \sum_{h=1}^{H} \frac{L_{\max}}{B_h} \qquad (2)$$

where L_i denotes the max. packet size for a flow, L_{max} is the max. size of a packet permitted in the network and B_h is the overall bandwidth on link *h*.

- Each flow is assumed to be regulated by the Leaky Token Bucket scheme with bucket depth σ and the token rate ρ. The ρ and σ can be viewed as the maximum burst size and the long term bounding rate.

Load Balancing Algorithm

- It is assumed that σ is equal to guaranteed rate R_i for the service class i (Eq. 1).
- If there are N_i active flows then the max. burst size ρ is assumed to be equal to $N_i L_{max}$.
- Hence, worst-case delay can be presented as:

$$D_{i,l} \leq \frac{N_{i,l} L_{\max} + 2(K-1)L_i}{R_i} + \sum_{h=1}^{H} \frac{L_{\max}}{B_h} \qquad (3)$$

- When new ith service class connection request appear, the guaranteed rate (Eq. 1) and worst-case delay bound (Eq. 3) are recalculated and obtained values are used for determining the price for each path.
- The price of the path is dependent on the resource consumption as well as the congestion level of the path and it is defined as follows:

$$r_{i,l} = \frac{D_{i,l} R_{i,l}}{\lambda_l H}, \qquad (4)$$

- where coefficient λ denotes the priority of the path.
- Because the number of busy connections on LSP l in class i is $N_{i,l}$ and the price charged per unit time for a single connection is $r_{i,l}$, the revenue paid by the ith class customer on LSP l is the product of $N_{i,l} r_{i,l}$.
- Let $x_{i,l}$ be a binary variable such that $x_{i,l}=1$, when connection in class i is transferred using LSP l, otherwise $x_{i,l}=0$, $i=1,\ldots,m$, $l=1,\ldots,L$.

Load Balancing Algorithm

The main goal of the proposed model is to maximize the total revenue R

$$\text{maximize } R = \sum_{l=1}^{L} \sum_{i=1}^{m} N_{i,l} r_{i,l} x_{i,l} \qquad (5)$$

subject to

$$\sum_{i=1}^{m} x_{i,l} = 1, \qquad \forall l = 1,\ldots, L$$

$$x_{i,l} \in \{0,1\}, \qquad \forall i = 1,\ldots, m$$

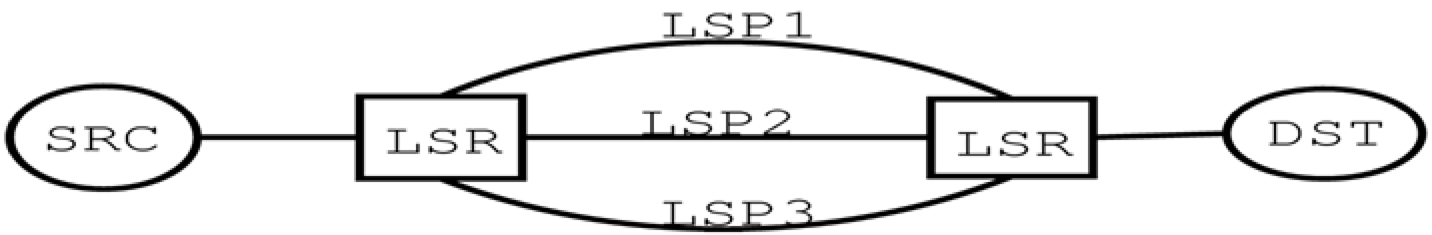
$$\forall l = 1,\ldots, L$$

$$B_i < R_{i,l}, \qquad R_{i,l} \geq 0$$

$$D_{i,l} < D_{i,\max}, \qquad D_{i,l} > 0,$$

$R_{i,l}$ = guaranteed rate
B_i = req. bandwidth
$D_{i,max}$ = max. allowable delay
$D_{i,l}$ = delay on path l
N_i = number of packets
$r_{i,l}$ = price of the path

Simulations



- In the simulations, the arrival rates of connection requests and the mean holding time of a connection are exponentially and uniformly distributed random variables, respectively.
- The traffic sources are divided between the three traffic classes (gold, silver and bronze) with different set of QoS parameters.
- All traffic from *SRC* to *DST* is carried over MPLS network by using one of the parallel LSPs.
- All MPLS nodes use WFQ.

Simulations

Parameters of the service classes

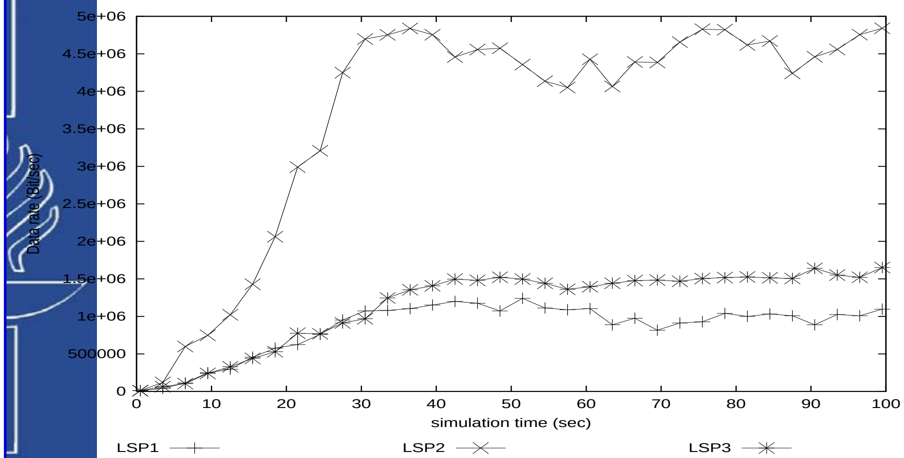
Class	Type	Max flows	weight	Buffer length (pkts)	Bandwidth (kbit/sec)	Delay (msec)
Gold	Video (H.263)	10	0.6	50	280	80
Silver	Video conf. (H.263)	18	0.25	100	67	150
Bronze	Exponential (UDP)	-	0.15	170	-	-

- The performance of the proposed model is compared with three dynamic load balancing approaches:
  - Round Robin (RR)
  - Random routing (RAN)
  - Lightest Loading routing scheme (LL)

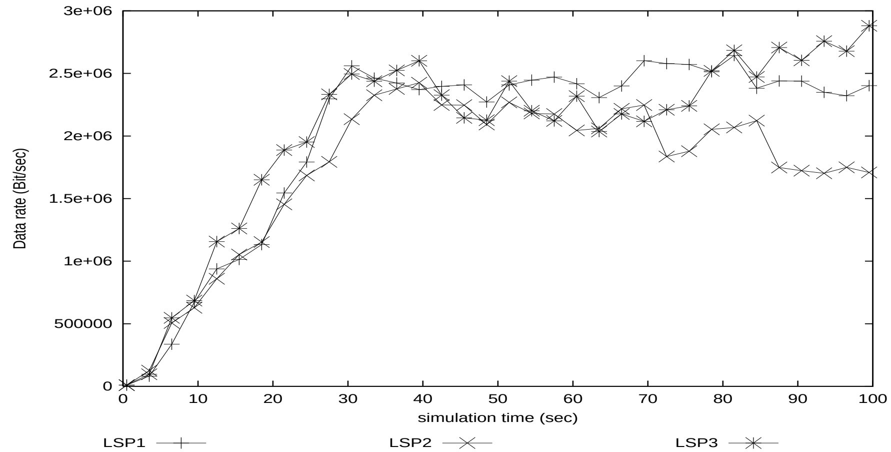
Scenario 1: Low Utilization

- Figures 2(a)-2(d) depict the utilization of each LSP during the simulation with all the load balancing approaches.
  - All the other models distribute traffic load more evenly between candidate paths and consume therefore relatively larger amount of network resources
- Mean end-to-end delays remain low with all the approaches due to small utilization of the paths, as can be seen in Fig. 3.

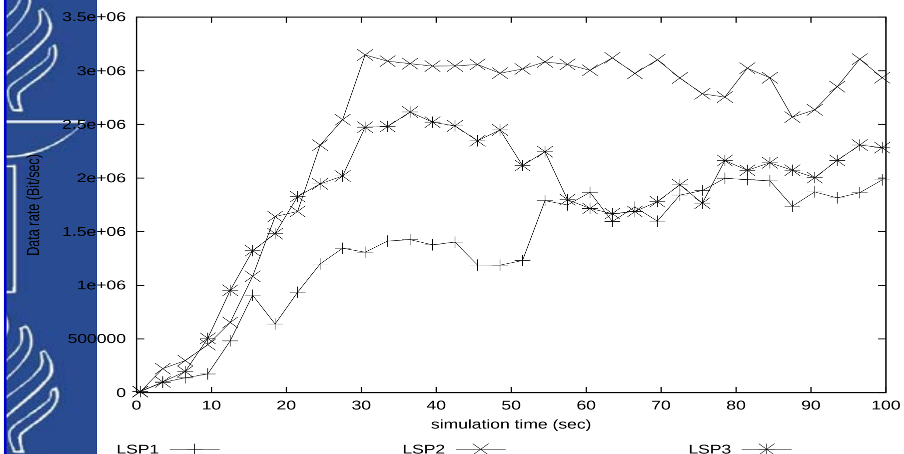
Scenario 1: Low Utilization



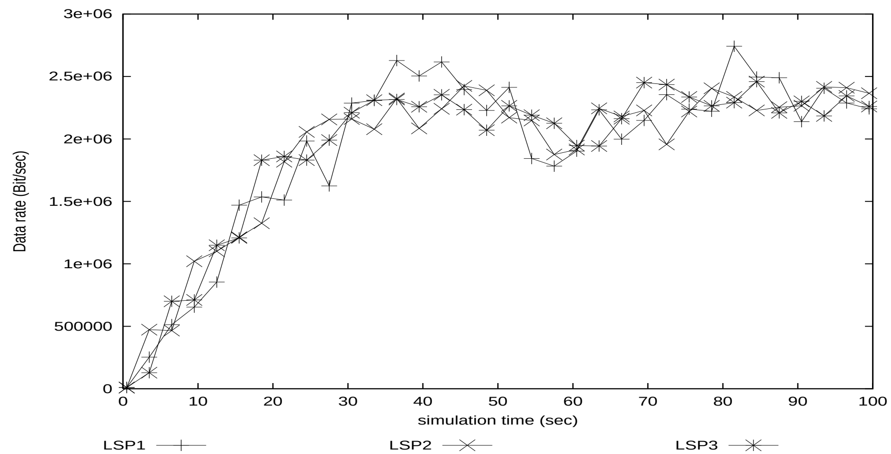
(a) Proposed model



(b) RR approach



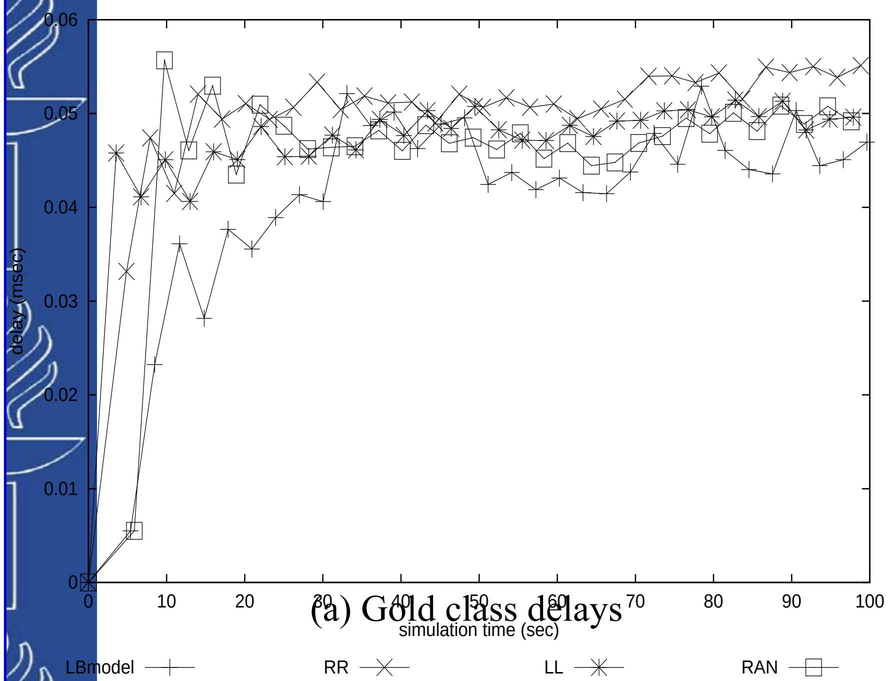
(c) RAN approach



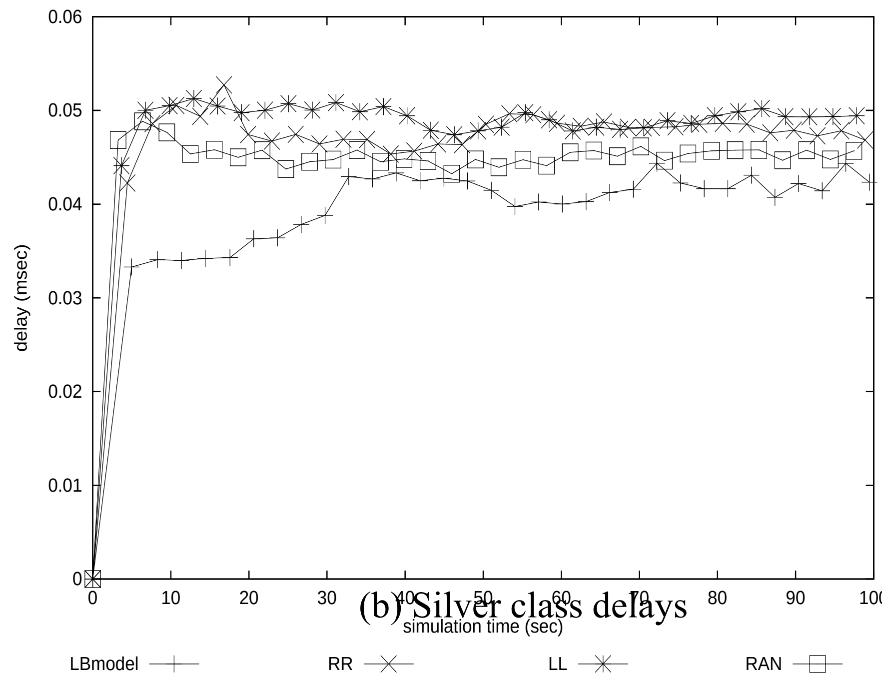
(d) LL approach

Figure 2. Paths' utilizations as a function of simulation time in scenario 1

Scenario 1: Low Utilization



(a) Gold class delays



(b) Silver class delays

Figure 3. Mean delays as a function of the simulation time in scenario 1

Scenario 1: Low Utilization

- There is no great difference between approaches in terms of network revenue, as can be seen in Fig. 4.
  - However, the proposed model produces the largest revenue because it distributes more flows to the shortest and therefore the most expensive path (see Eq. 4).

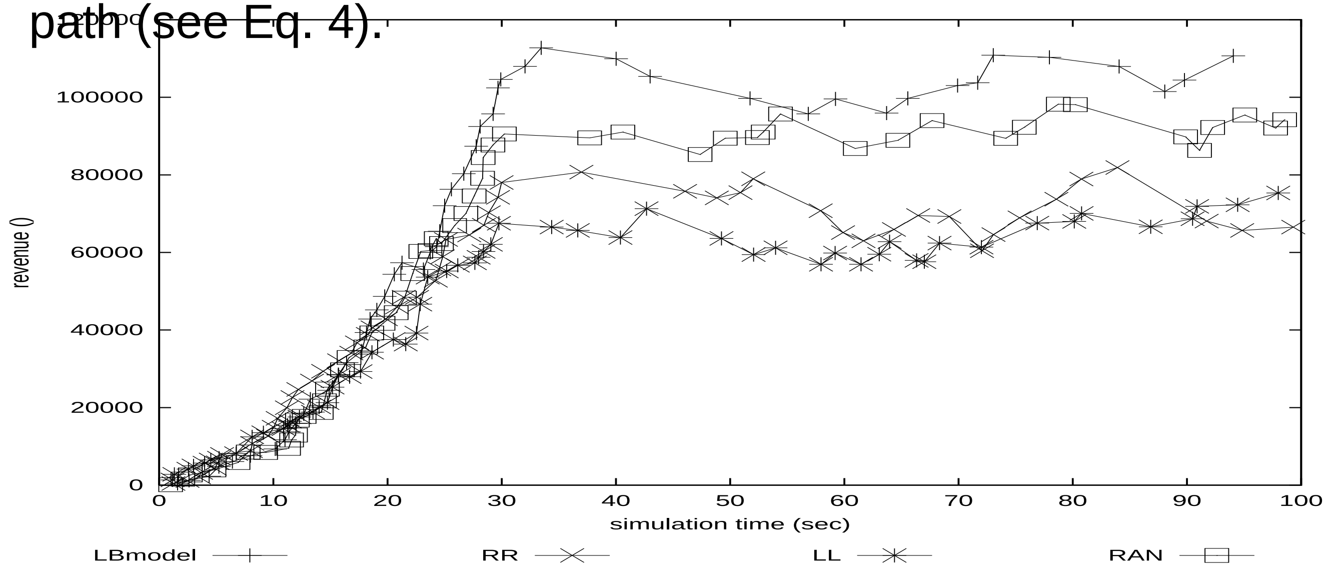
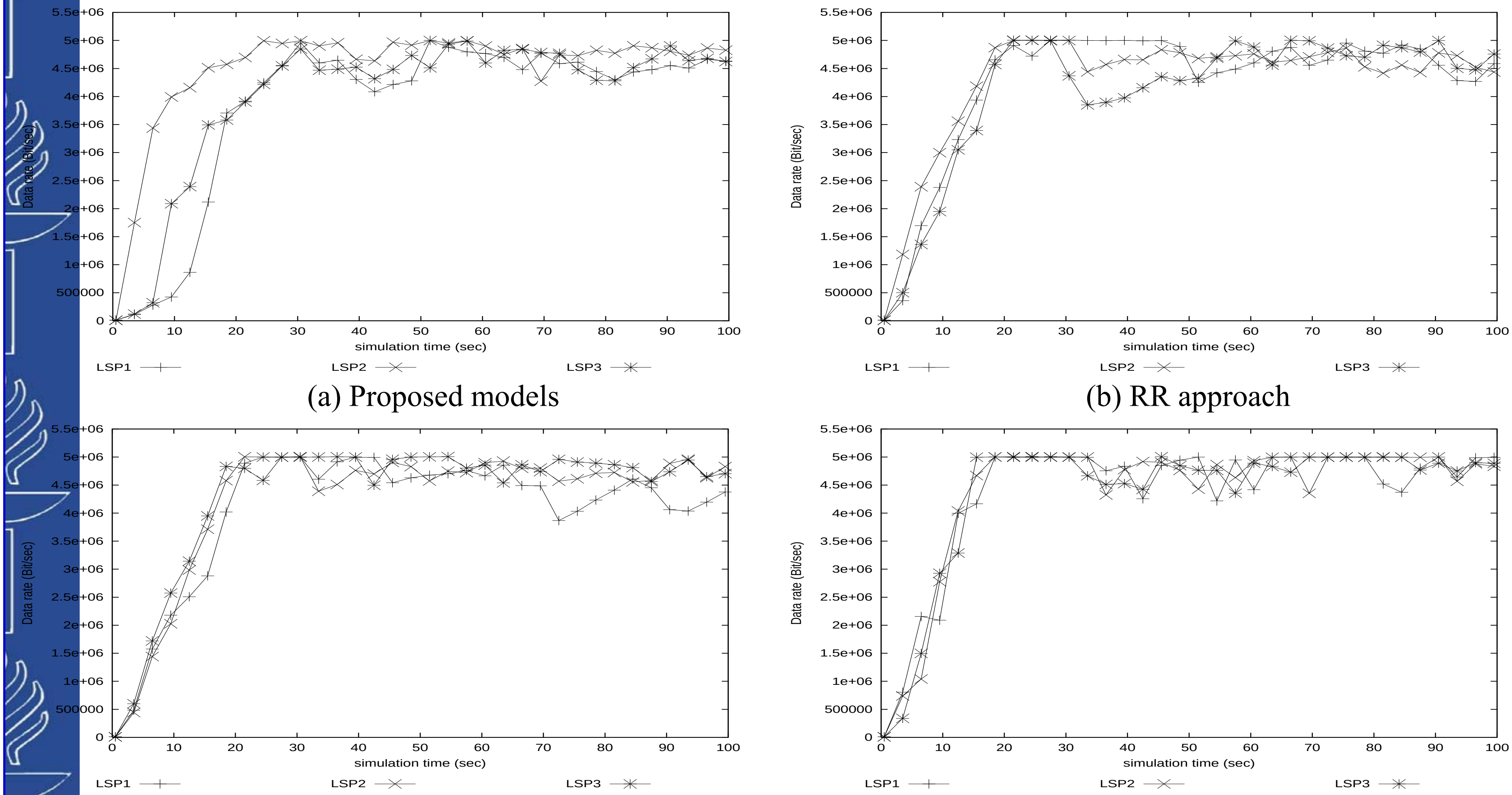


Figure 4. Evolution of revenue in scenario 1

Scenario 2: High Utilization

- The number of connection requests in each traffic class is higher than scenario 1 -> network's utilization increases (Fig. 5).
- The number of active traffic flows is restricted due to bandwidth constraint in Eq. 5 and therefore rate R_i (Eq. 1) can be guarantee to each traffic flows belonging to service class *i.*
- Figure 6 depicts gold and silver service classes' mean end-to-end delays during the simulation.
- The proposed model can fulfill delay requirements while other approaches are not capable of providing delay gurarantees.

Scenario 2: High Utilization



(a) Proposed models

(b) RR approach

(c) RAN approach

(d) LL approach

Figure 5. Paths' utilizations as a function of simulation time in scenario 2

Scenario 2: High Utilization

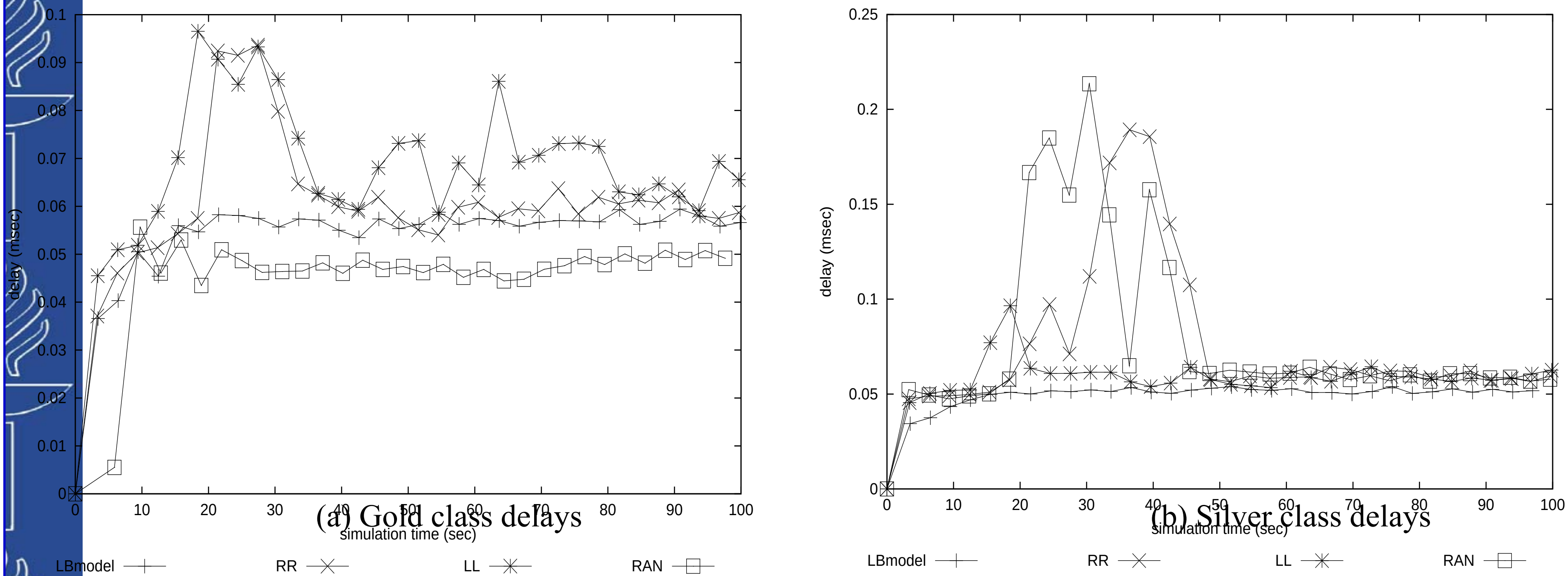


Figure 6. Mean delays as a function of the simulation time in scenario 2

Scenario 2: High Utilization

- In terms of revenue, the proposed model performs much better than other approaches in higly loaded network (Fig 7.).
  - Since the proposed model consider not only utilization but also the price of the path, it is capable of selecting the path producing the highest revenue.
  - In this scenario, the revenue is improved more than 20% compared to RR and RAN approaches and about 50% compared to LL approach.

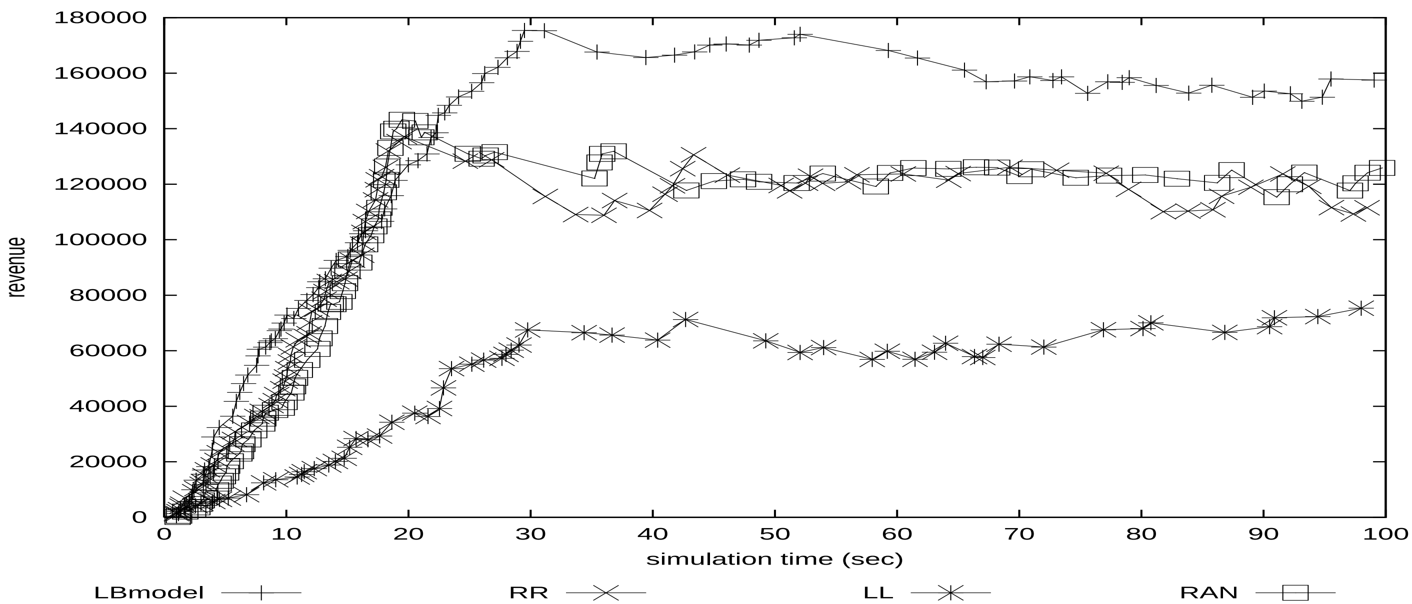


Figure 7. Evolution of revenue in scenario 2